5. Study on High Dielectric Constant Ceramics. (XX)

Tuning Fork and Vidrating Reed Driven by $BaTiO_3$ Ceramics

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Tuning fork oscillators of electromagnetic type are generally used. In the oscillator of this type constituent material of vibrator must have following properties:

i) Temperature coefficient of natural frequency is zero or very small.

ii) It must be ferromagnetic.

Furthermore, vibrator must be fixed relatively to magnets, and clearance between fork and magnets must be invariant.

In the tuning fork of piezoelectric type, such conditions are not always necessary. The idea of tuning fork driven by piezoelectric element adhered on fork surface may not be a new one. But there have never been brought in practical use, because the quartz crystal has high impedance and Rochelle salt etc. are not reliable in respect to their mechanical strength and hygroscopicity. By using $BaTiO_3$ ceramics, these defects can be removed and all the difficulties in electromagnetic type are decreased or overcome and the apparatus can be made more simpler and smaller.

Experiments have been carried out upon several samples of this type, and comparatively good results were obtained which will be described here.

Piezoelectric Type Tuning Fork:

In the electromagnetic type, electromagnetic attractive force acts at the loop of vibration in parallel to the motion of the vibrator. But in piezoelectric type, as piezoelectric element is directly adhered on vibrator surface and their electrostrictive force work in parallel to the surface, it is considered that the most suitable position, where piezoelectric element is to be situated, is the nodal point of vibration. As the points that have minimum amplitude were found to be situated at P,G in Fig. 1 by

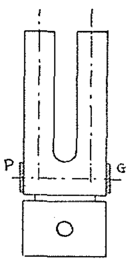

Fig. 1.

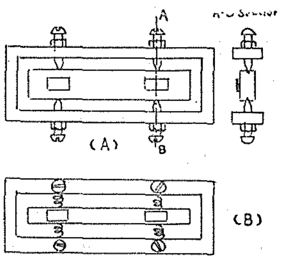

Fig. 3.

the measurement of amplitude distribution on the surface, $BaTiO_3$ plate which has silver electrodes on both surface were adhered on these points. Phosphor-bronze strips were soldered directly on electrodes of P,G as current feeders, and P is to be connected to plate circuit and G to grid circuit of oscillator (Fig. 2). Elements

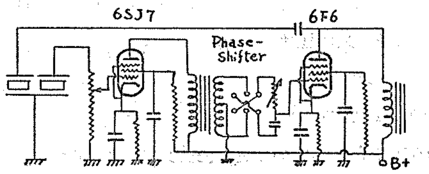

Fig. 2.

were polarized under high voltage D.C source before use. Fundamental vibration can be excited when both elements are polarized in the same direction, and P and G are in the same phase. When some phase difference exist between them, higher harmonic vibrations can be excited. Supporting device of this fork become very easy, because there is nothing to be fixed relatively. Frequency deviation due to the adherence of the elements was neglisible small, as the mass of the piezoelectric elements were very small compared to that of vibrator.

Piezoelectric Type Vibrating Reed:

The idea to produce a tuning fork of piezoelectric type may be applied similarly to a vibrating reed of the same type. In this case, as the mode of vibration is very simple, method and the position where elements must be adhered are easily determined. Resonant frequency of the vibrating reed is represented by the following equation as is well known,

$$w_m = \frac{a_m}{l^2} \frac{t}{\sqrt{12}} \sqrt{\frac{E}{\rho}}$$

where l : length in cm,

t : thickness in cm,

$a_m = 4.73$ for fundamental vibration.

Nodal points are determined by the following equation :

$$l_1 = 0.2242\, l,\ 0.7758\, l$$

where l_1 is distance between node and one end.

Two types of supporting system were examined as shown in Fig. 3 :

(A) Fixed at the nodal points of vibrator by 4 screws which have needle point.

(B) Hanged at the nodal point of vibrator by 4 springs to frame.

Dimensions and frequency of tested samples are shown in the following table.

Sample	Material	l(mm)	t(mm)	l_1(mm)	f(kc)	Type of Supporting
No. 1	Steel	72.4	4.0	16.2	4.01	(A)
No. 2	〃	56.5	5.0	12.7	8.01	〃
No. 3	Elinvar	40.0	3.14	8.97	9.405	(B)

Size of $BaTiO_3$ elements were $8 \times 8 \times 0.5$ (mm) for No. 1, No. 2 and $3 \times 5 \times 0.3$ (mm) for No. 3. In every case, they were operated very successfully. As in the case of tuning fork, fundamental vibration was excited when two elements are in the same phase, and if proper phase difference is given harmonic vibration was excited. Q value of vibrator was abowt 2000 — 5000, and in (B) type Q was greater than (A) type. Internal loss was about 20 db in every case.

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6. Study on High Dielectric Constant Ceramics. (XXI)

$BaTiO_3$ Ceramics as a Material of Dielectric Amplifier

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It was known that dielectric amplification using ferroelectric property is possible according to the same principle as the magnetic amplifier using ferromagnetic property, and such amplifier has attracted much attention since $BaTiO_3$ ceramics were found out. However, few reports and data on dielectric amplifier, the production of materials or the application of amplifier, were published. Recently, the characteristics especially concerning amplification in dielectric properties of $BaTiO_3$ ceramics, were inspected and the experimental results were put in order mathematically in our laboratory.

As the permittivity is affected by d-c bias most sensitively near Curie temperature, it is desirable for the material of amplifier to have the Curie point at room temperature. Such materials are easily made by mixing titanate of Sr, Zr or Sn in $BaTiO_3$ because the Curie point decreases in proportion to the quantity of Sr, Zr or Sn. The materials having such characteristics that the permittivity is not largely influenced by the temperature, have been made already. The characteristics of permittivity to d-c bias were measured about the materials having sharp temperature characteristics (A-kind material) and flat temperature characteristics (B-kind material), and results were compared with theoretical ones.

Characteristics of permittivity to d-c bias:

The characteristics of permittivity to d-c bias will be mathematicaly represented by assuming the suitable equation to the saturation characteristics of ferroelectric materials. Many equations representing saturation characteristics have been presented, from which two equations suitable for $BaTiO_3$ ceramics were selected.

$$E = aD + bD^3 \qquad (1)$$

$$E = \alpha \sinh(\beta D) \qquad (2)$$